High-Speed Turbulent Boundary Layers and Interactions with Shock Waves

Aeronautics Research Mission Directorate

The design of supersonic and hypersonic vehicles depends strongly on the accurate prediction of turbulent flow characteristics and interactions in high-Mach boundary layers. Boundary layer turbulence has first-order impacts on aerodynamic heating, surface ablation, drag, and control of hypersonic vehicles during ascent and descent.

We are performing simulations of high-speed turbulent boundary layers, using a high-order hybrid shock-capturing scheme and a novel recycling-recycling approach to efficiently resolve the spatially developing boundary layer. Our results have shown that turbulence statistics for high-Mach number flows collapse to their incompressible counterparts when scaled using wall quantities, indicating that these statistics are affected primarily by variable thermodynamic properties rather than flow compressibility.

We are also performing simulations of shock wave turbulent boundary layer interaction (STBLI). A key element of STBLI is the unsteadiness of the shock wave and separation bubble, which can oscillate at a frequency significantly lower than the characteristic frequency of the incoming boundary layer. To capture these phenomena, we are utilizing large eddy simulation (LES), with a 6th-order compact difference scheme and localized artificial diffusivity for shock capturing, to simulate two canonical STBLI cases: the compression ramp, and the impinging oblique shock.

This work will help develop fundamental understandings of turbulent boundary layer characteristics and the associated surface heat fluxes, which will be critical to the design of next-generation high-speed aircraft and aerospace reentry vehicles.

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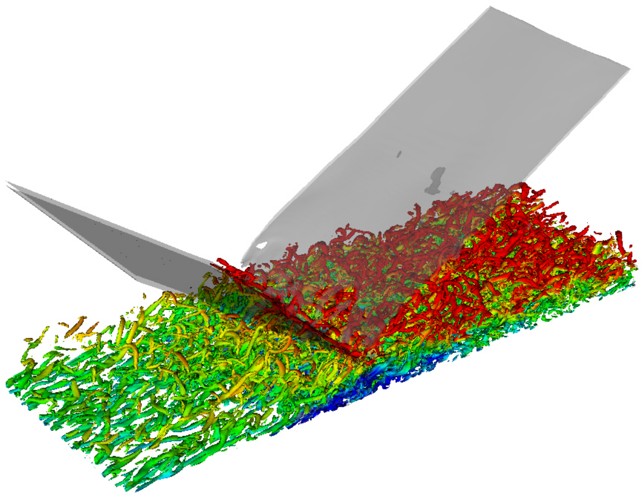

Oblique shock impinging on a hypersonic turbulent boundary layer for a Mach 2.05 flow over an 8-degree wedge angle. Isosurfaces of Q-criterion are colored by the streamwise momentum. The grey surfaces indicate location, and the dark blue surfaces indicate separation regions. *Sanjiva Lele, Parviz Moin, Stanford University*